www.rericjournal.ait.ac.th

Experimental Studies on Performance and Emission Characteristics of Diesel Engine Fuelled with Neem Oil Methyl Ester Blends

Gopinath D.[*1] and E. Ganapathy Sundaram[+]

Abstract – The world energy supply for transportation sector mainly depends on fossil liquid fuels and 90% of these fuels are utilized for energy generation and transportation. Fossil fuel availability is limited and its use increases the environmental pollution. Hence there is a need to find out an alternate fuel which will be available in a sustainable form and would also reduce environmental pollution. Bio-fuel is a good option to meet these requirements. In this view studies pertaining to the use of Neem Oil Methyl Ester (NOME) as an energy source for internal combustion engine has been taken. This paper presents the performance, emission and combustion characteristics result obtained from the experimental study on the NOME – diesel blends in a single cylinder stationary diesel engine. The 20% and 30% blends are used and the study found that 20% blends gives better performance and lower emissions compared to diesel and B30 blend.

Keywords – Alternate fuel, bio-diesel, emissions, neem oil methyl ester, heat release rate.

1. INTRODUCTION

Demand for energy in transportation sector is continuously increasing due to the growing in number of vehicles for different transportation sectors. Diesel is one of the major contributors to get energy in the transportation sector in the form of fuel. The increase in demand for diesel leads to investigate the identification of new alternate for diesel. The utilisation of a renewable fuel, such as biodiesel in diesel engines in the form of blends, could reduce emissions such as the particulates, Carbon monoxide (CO) and Hydro Carbon (HC). As biodiesel has a higher ignition quality (Cetane Number (CN) > 58) than diesel (CN = 50), it is more suitable for diesel engines. Biodiesel can be derived from vegetable oils and fats. Biodiesel has a higher flash point and cetane number, lower sulphur and aromatics content than petroleum diesel fuel. It could also be expected to reduce exhaust gas emissions due to its higher oxygen content (1). Biodiesel is a primarily focused liquid alternative fuel for Compression Ignition (C.I) engines. Vegetable oils have comparable energy density, Cetane number, heat of vaporization and stoichiometric air–fuel ratio with that of the diesel fuel. Methyl, ethyl or butyl esters produced by esterification process of different kinds of vegetable oils, animal fats and algae are commonly referred as biodiesel (2). The production of non-edible oils in India is as follows: Mahua-180; Sal-180; Karanja-55; Kusum-25; and Ratanjyot-15 kilo tons per year. Mahua (Madhuca Indica) oil is non-edible oil and available plenty in India. The two major species of genus Madhuca found in India are Madhuca Indica (latifolia) and Madhuca longifolia. Madhuca latifolia is a medium sized to large deciduous tree, distributed in South India and evergreen forests. The tree is planted in most parts of India, propagating either by itself or its own seeds (3). Biodiesel fuels also have an interesting potential to reduce chemical emissions. However, the effect of biodiesel is specific for each of the different pollutant species, and depends on the type of engine, engine operating parameters and quality of biodiesel (4).

Comprehensive research work is being carried out all over the world to replace diesel with vegetable oils, their esters and the blends of oils and esters with diesel for running C.I engines. Altin *et al.* studied the performance and exhaust emissions of a diesel engine using vegetable oil and their methyl esters (raw sunflower oil, raw cottonseed oil, raw soybean oil and their methyl esters, refined corn oil, distilled opium poppy oil and refined rapeseed oil) and compared the results with pure diesel. The study found that performance and emission characteristics of vegetable oil methyl esters are closer to the diesel fuel. The methyl esters smoke opacity values are between those of diesel fuel and raw oil fuels. The study also found that heavier molecules of hydrocarbons present in the vegetable oil fuels leads to greater smoke opacity percentages as compared to others (5). The performance and emission characteristics of Rubber Seed Oil Methyl Ester (RSOME) in compression ignition engines with various blends of biodiesel–diesel was analyzed by Ramadhas *et al*. Maximum Brake Thermal Efficiency (BTE) of about 28% and low emission and Brake Specific Fuel Consumption (BSFC) were obtained at B10 blend (6). Canakci and Van Gerpen used methyl esters of yellow grease and soyabean as biodiesel and found significant reductions in the CO, HC, and smoke emissions compared with diesel fuel. Thermal efficiency level of yellow grease and soya bean biodiesel are nearer to diesel but BSFC for biodiesel is higher than diesel (7). Balaji and Cheralathan, studied effect of antioxidant with NOME for controlling Nitrogen dioxide (NOx) emission in Direct Injection (DI) Diesel engine. Anti oxidant additive (Butylated hydroxytoluene) is mixed in

[*]Department of Mechanical Engineering, Panimalar Institute of Technology, Chennai-600123, Tamil Nadu, India.

[+]Department of Automobile Engineering, Velammal Engineering College, Chennai – 600066, Tamil Nadu, India.

[1]Corresponding author: Tel: +91 9543366803.
E-mail: gopi.vlr6@gmail.com.

various proportions (100–400 ppm) with methyl ester of neem oil. Antioxidant additive with NOME reduced NOx emission by 19.99% at full load condition compared to neat biodiesel. The HC, CO and smoke emissions for all mixtures are found to be slightly higher and Carbon dioxide ($CO_{2)}$ emission is slightly lower due to the disturbance during combustion (8).

Muralidharan and Vasudevan used waste cooking oil methyl ester as a biodiesel in variable compression ratio multi fuel engine with 20%, 40%, 60% and 80% biodiesel blended with diesel. The BTE of the blend B40 is higher than that of diesel at higher compression ratios. The specific fuel consumption of blend B40 is lower than that of all other blends, this may be due to fuel density, viscosity and heating value of the fuels. For B40 and diesel, the maximum brake power was obtained at the compression ratio of 21. Waste cooking oil blends given higher combustion pressure at high compression ratio due to longer ignition delay, maximum rate of pressure rise and lower heat release rate (9). Ekrem Buyukkaya *et al*. used neat rapeseed oil and its blends (5%, 20%, 70% and 100%) in diesel engine. The use of rapeseed oil produced lower smoke opacity (up to 60%), and higher BSFC (up to 11%) as compared to diesel fuel. CO emissions of B5 and B100 fuels were found to be 9% and 32% lower than that of the diesel fuel, BSFC of biodiesel at the maximum torque and rated power conditions were found to be 8.5% and 8% higher than that of the diesel fuel (10). Banapurmath *et al*. studied the performance of CI engine fuelled with diesel, honge, rice bran, and neem oils with producer gas- diesel under dual fuel mode. They reported that smoke and NO emissions are lower. However, BTE is lower and HC and CO emissions are higher (11). Nantha Gopal *et al*. conducted Waste Cooking Oil (WCO) methyl ester blends as a fuel in diesel engine to find its combustion and emission characteristics. Use of WCO blends resulted in lower thermal efficiency, carbon monoxide, unburned hydrocarbon and smoke opacity and the other hand specific energy consumption and oxides of nitrogen are found to be higher than diesel. Combustion characteristics of WCO blends resulted similar to diesel (12).

Almeida *et al*. conducted tests using 100% palm oil on direct injection four-stroke 70 kW diesel-generator. The results proved that a diesel-generator set can be adapted to run with palm oil. Increasing the palm oil temperature increased performance and endurance of the diesel generator compared to ambient conditions. The deposits on the cylinder head was high when the engine operated with palm oil heated at 50°C and acceptable levels when heated at 100°C (almost similar to the operation with diesel fuel). However, other engine modifications are required to improve lubricating oil degradation, performance, emissions and to reach a more efficient combustion (13). Reddy and Ramesh [14] conducted tests with neat Jatropha oil on a single cylinder, constant speed, direct injection diesel engine by changing the engine operating parameters. Tests shown that advancing the injection timing from the base diesel value and increasing the injector opening pressure increase the BTE and reduce HC and smoke emissions significantly. Enhancing the swirl has only a small effect on emissions. The ignition delay with Jatropha oil is always higher than that of diesel under similar conditions. Improved premixed heat release rates were observed with Jatropha oil when the injector opening pressure is enhanced. When the injection timing is retarded with enhanced injection rate, a significant improvement in performance and emissions were noticed. Government of India is encouraging to use of Jatropha oil as a Bio fuel in India (14). From the literature survey it is found that the use of biodiesel decreases the environmental pollution and increase the efficiency of diesel engine. Neem oil methyl ester is one of the biodiesel and it is available in large quantity. The literature related to performance and emission characteristics of NOME are limited and little attention is also given for its combustion characteristics. In this regard the present research work aims that to study the feasibility of NOME as a blend for diesel engine. The experiments were carried out with the NOME blends (B20 and B30) with diesel. The performance, emission and combustion characteristics obtained were analysed in detail for both blends and diesel.

2. EXPERIMENTAL SETUP AND PROCEDURE

2.1 Experimental Setup

A single cylinder, four-stroke, air cooled, direct injected diesel engine was used in this study. Figure 1 shows the schematic diagram of the experimental setup. The technical specifications of the engine are given in Table 1.

An automatic solenoid controlled type burette was used to measure the fuel consumption. An air box fitted between the engine intake manifold and the exhaust pipe is used to accumulate sufficient air. A manometer fitted in the air box shows the readings of the water head which is used to calculate the air consumption of the engine. A K-type thermocouple with a temperature indicator fitted in the exhaust pipe indicates the temperature of the exhaust gas. A Kistler water cooled piezoelectric transducer which was mounted in the cylinder head was used to measure the combustion pressure with crank angle encoder with a resolution of 0.1^0 CA was given to the same instrument to measure crank angle. AVL444 exhaust gas analyser was used to measure the emissions. The gas analyser specifications are HC measurement range of 0-20000ppm with a resolution of 1ppm, CO measurement range of 0-10% with a resolution of 0.01%vol, CO_2 measurement range of 0 to 20% with a resolution of 0.1%vol, O_2 measurement range of 0-25% with a resolution of 0.01%vol and NOx measurement range of 0-5000ppm with a resolution of 1ppm. AVL437C diesel smoke meter was used to measure the smoke intensity. The measurement range is 0-100% with a resolution of 0.1%.

2.2 Experimental Procedure

The NOME was blended with diesel fuel in a volume of 20% and 30%. Initially, the engine was operated with diesel and base data's were taken and noted, then the experiments were conducted with B20 and B30 blends and readings were taken. For each condition the experiments were conducted with three times and average value was taken for calculation. The engine was stabilized before taking all measurements. The results obtained with blends were compared with the diesel.

2.3 Neem Oil

The scientific name of neem is azadirachta indica. It belongs to the family meliaceae. The kernals contains 40% to 50% of an acrid bitter greenish yellow to brown oil with strong disagreeable garlic like odour (15). This bitter taste is due to the presence of sulphur containing compounds like Nimbin, Nimbidin and Nnimbosterol. Raw oil contains four significant saturated fatty acids, of which two are palmitic acid and two are stearic acid. It also contains polyunsaturated fatty acids such as oleic acid and linoleic acids. The oil is used for illumination, soap making, pharmaceuticals, cosmetics and medical fields.

2.4 NOME Preparation

Chemically, transesterification means taking a triglyceride molecule or a complex fatty acid, neutralizing the Free Fatty Acids (FFA) (around 13% in the current raw oil), removing the glycerine and creating an alcohol ester (16). The FFA composition of neem oil is shown in table.2.

Table 1. Specification of engine.

Particulars	**Specifications**
Engine Make	**Kirloskar TAF1**
Type	Four stroke, Diesel engine
Number of cylinder	1
Rated power	4.4 KW, 1500 rpm
Bore x Stroke	87.5 mm x 110 mm
Compression ratio	17.5:1
Fuel Injection timing BTDC (^{0})	23
Number of injector nozzle holes	3
Injection Pressure	220 bar

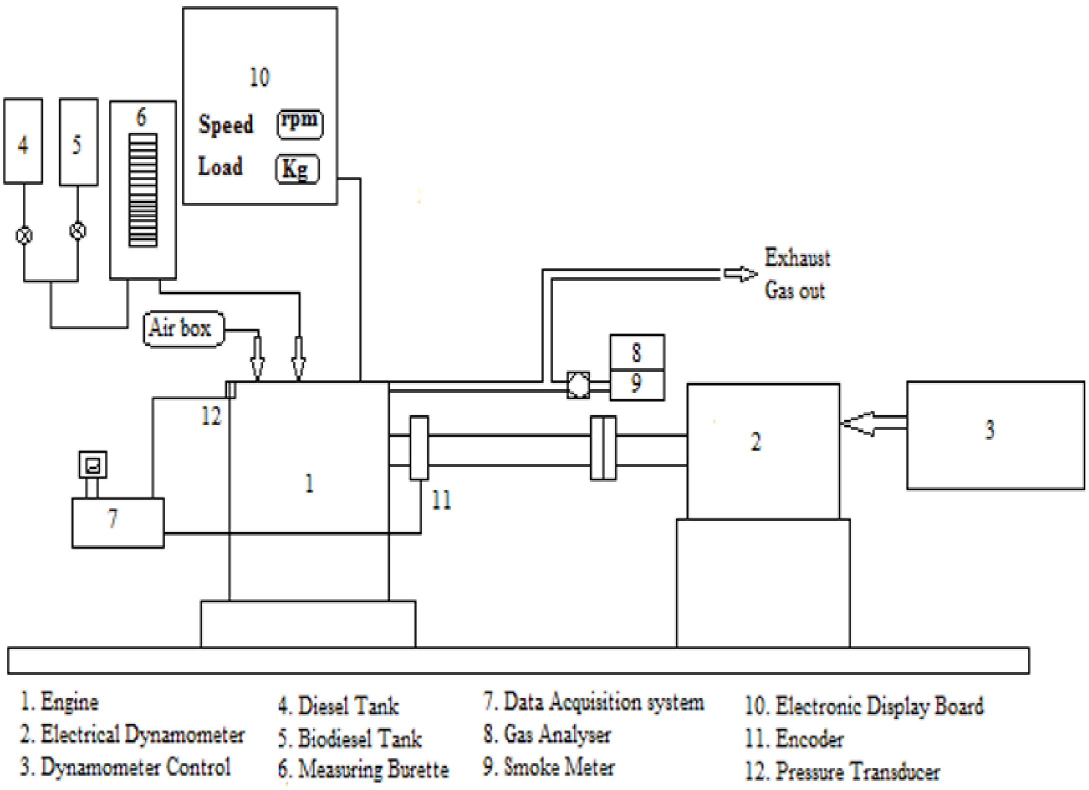

Fig. 1. Schematic diagram of experimental setup.

Table 2. FFA composition.

Fatty acid	Formula	Structure	% Composition in neem oil
Palmitic	$C_{16}H_{32}O_2$	16:0	13.6–16.2
Stearic	$C_{18}H_{36}O_2$	18:0	14.4–24.1
Oleic	$C_{18}H_{34}O_2$	18:1	49.1–61.9
Linoleic	$C_{18}H_{32}O_2$	18:2	2.3–15.8
Arachidic	$C_{20}H_{40}O_2$	20:0	0.8–3.4

Source: [20].

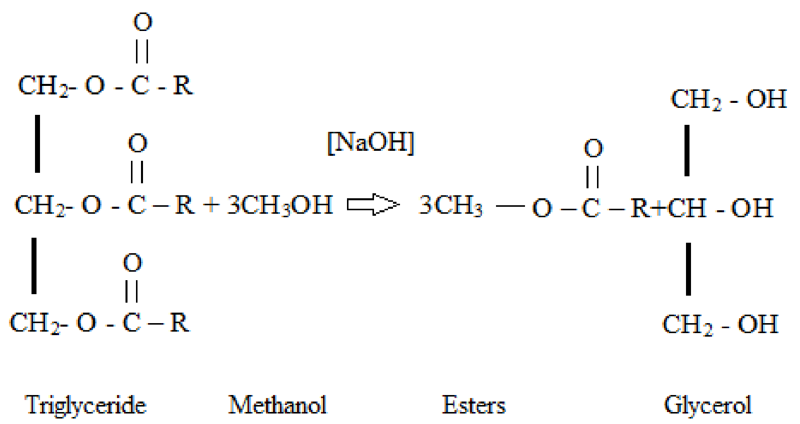

Fig. 2. General transesterification process.

The raw neem oil was transesterified using methanol in presence of NaOH catalyst. It is found that 55°C, 0.75% (w/w) catalyst and one hour reaction time is optimum for transesterification of raw neem oil. For transesterification in laboratory, raw neem oil was heated in a round bottom flask. NaOH was dissolved in methanol in a separate vessel and was poured in the round bottom flask, while stirring the mixture continuously. The mixture was stirred while being maintained at 55°C for approximately one hour. The reaction products were kept in a separating funnel for about 24 hours. The products formed during transesterification were NOME and glycerol. The glycerol formed is deposited at lower layer during gravity separation and it was separated. The ester was washed with 10% volume by volume warm water (70°C) and kept for about 24 hours for removal of catalyst by dissolution in water to meet the specifications of ASTM D6751. The properties of NOME and other methyl esters are listed in Table 3.

3. RESULT AND DISCUSSION

(Performance, Emissions and Combustion Characteristics)

A wide range of experiments were carried out at different load conditions to examine the effect of adding NOME to diesel on the BTE, Exhaust Gas Temperature(EGT), and HC, CO, CO_2, NO_X and smoke emissions. The tests were carried out with B20, B30 and diesel at 0%, 25%, 50%, 75% and full load conditions.

3.1 Brake Thermal Efficiency

The variation of BTE with different load conditions is shown in Figure 3 for diesel, blends B20 and B30. The study found that increase in BTE with increase in load for all the cases. This is due to the reduction in heat loss and increase in power developed with increase in load (7). At lower load conditions the variation of BTE between three cases is observed as low compared to higher load conditions. Notable BTE variation at higher loads is due to improvement of diffusive combustion phase on account of oxygen enrichment in the NOME which leads to better combustion and higher BTE as compared to diesel. Around 1.5% rise in thermal efficiency is observed with B20 as compared to diesel at higher load conditions. At no load condition, BTE of B20, B30 and diesel is almost same. The lower BTE with respect to B30 as compared to B20 may be due to higher oxygen content in the B30 this leads to lean mixture during combustion.

3.2 Exhaust Gas Temperature

It is observed that EGT increases with increase in load for all the cases in this study and shown in Figure 4. Due to the high viscosity and low volatility of NOME blends were not adequately evaporated during main combustion phase and continued to burn in the late combustion phase which results higher EGT than diesel (23). The higher oxygen content in the NOME also leads to better combustion and increases the exhaust gas temperature. For B20 and B30 small variation in EGT is observed for all the load conditions.

Table 3. Properties of diesel fuel and other esters.

S. No	Property	Diesel	Neem oil Methyl Ester	Rubber Seed oil Methyl Ester	Cotton Seed oil Methyl Ester	Soya Bean oil Methyl Ester
1.	Chemical Formula	$C_{14}H_{24}$	$C_{17}H_{34}$ $COOCH_3$	$C_{18}H_{32}O_2$	$C_{54}H_{101}O_6$	$C_{18}H_{34}O_2$
2.	Density (kg/m^3)	827.1	890	924	850	884
3.	Specific gravity	0.835	0.920	0.874	0.874	0.885
4.	Calorific Value (MJ/kg)	42.50	39.81	36.50	36.8	39.76
5.	Viscosity (mm^2/s)	3.8	6.81	5.81	4.0	4.08
6.	Flash Point(^OC)	45	76	130	70	69
7.	Cetane Number	48	47	45	52	51.5

Source: [2], [7], [8], [21].

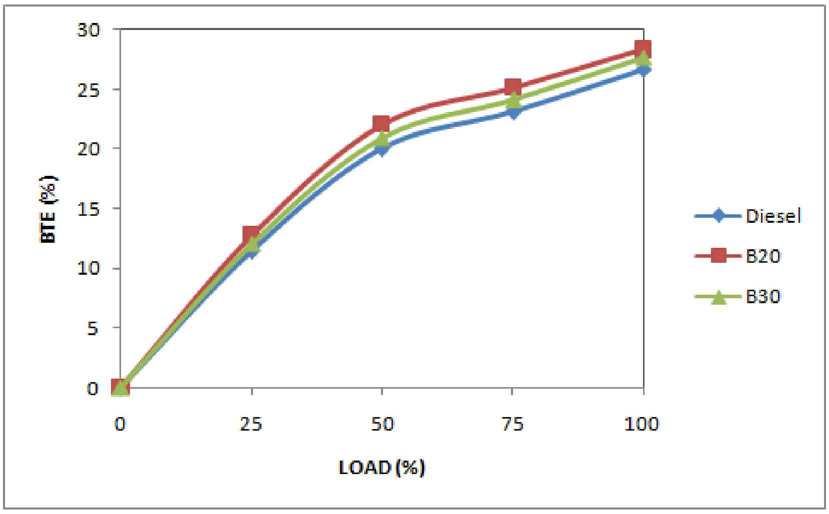

Fig. 3. Variation of BTE with load.

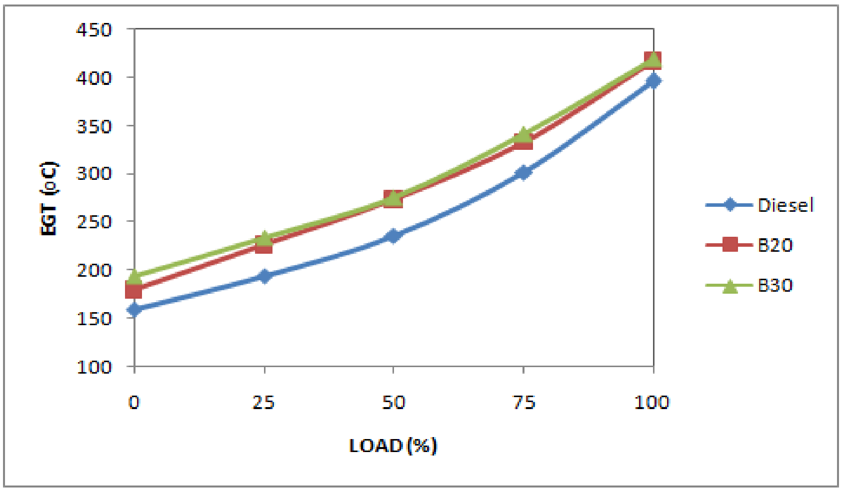

Fig. 4. Variation of exhaust gas temperature with load.

The EGT for diesel, B20 and B30 are 396^{0}C, 417^{0}C and 420^{0}C respectively at full load condition.

3.3 Hydrocarbon Emissions

The variation of Hydrocarbon emission is shown in Figure 5. It is observed that the variation of HC emissions with different load conditions for blends are having same trends with diesel and the values are lower than the diesel. The HC emission value of diesel, B30 and B20 at full load condition are observed as 24ppm, 22 ppm and 18 ppm respectively. The HC emission from B30 and B20 is 18% and 25% lower than diesel respectively. The presence of oxygen in the NOME leads better combustion and lower hydrocarbon emission as compared to diesel. Also, higher cetane number of NOME blends reduces the combustion delay, which causes to decrease in HC emissions.

3.4 Carbon Monoxide Emissions

Carbon monoxide is a by product of incomplete combustion, the CO present in the exhaust gas indicates that the combustion is incomplete. Higher CO emission is the presence of local rich mixtures at the core of the injection spray, which is deficient in air during the combustion process. Figure 6 shows that the variation of CO emissions with different load conditions for diesel and NOME blends. Lower CO values were observed for B20 and B30 blends as compared to diesel for all load conditions. This could be due to enrichment of oxygen in NOME which oxidizes CO in to CO_2 during combustion process and produce lower CO and higher CO_2 emissions.

3.5 Carbon Dioxide Emissions

CO_2 is not generally as a pollutant in an internal combustion engine. In perfect combustion all carbon in the fuel oxidizes with oxygen and converted into CO_2. The CO_2 emission release from the hydrocarbon fuel combustion depends on carbon content per mole of the fuel and availability of oxygen during combustion process. Carbon dioxide emission occurs due to complete combustion of fuel which is preferred as compared to CO emission. Variation in CO_2 against the load is shown in Figure 7 for both diesel and blends.

It is observed that higher CO_2 emission is observed for B20 and B30 blends compared to diesel. This could be due to high oxygen content in the blends. The lower CO_2 emission in B30 as compared B20 may be due to incomplete combustion in B30 blend.

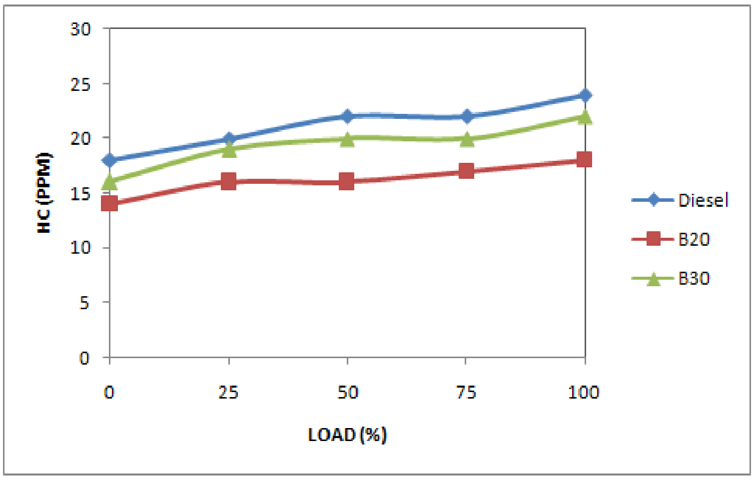

Fig. 5. Variation of hydrocarbon emission with load

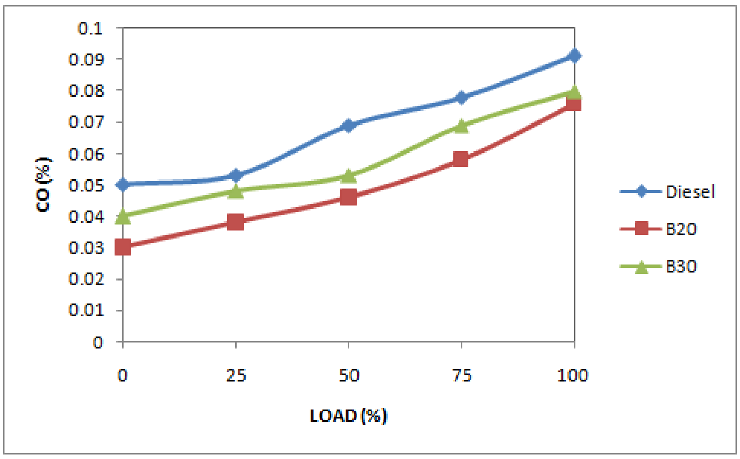

Fig. 6. Variation of carbon monoxide emission with load.

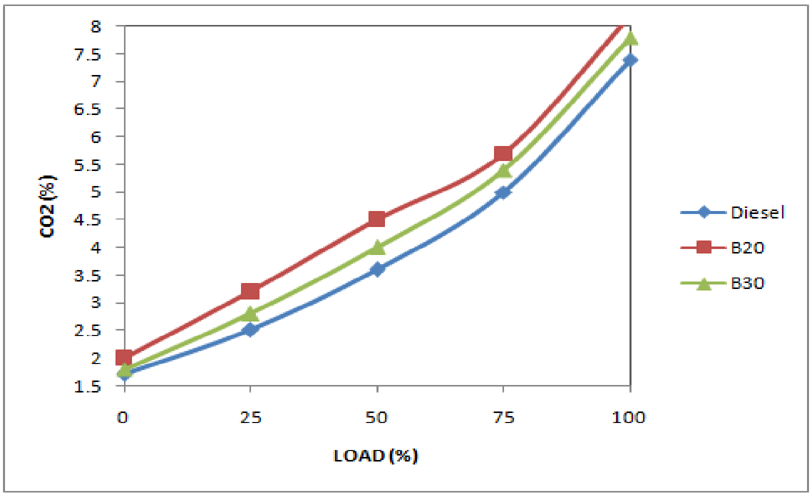

Fig. 7. Variation of carbon dioxide emission with load.

3.6 NOx Emissions

In diesel engine exhaust, NOx is predominantly composed of NO, with lesser amount of NO_2. Other oxides of nitrogen, such as N_2O, N_2O_5, NO_3 are negligible. In general, NOx formation mechanism is described as thermal NOx, prompt NOx and fuel NOx. Under most diesel engine combustion conditions, thermal NOx is believed to be the predominant contributor to total NOx. At high temperatures, occurring within the combustion chamber of a diesel engine, N_2 and O_2 can react through a series of chemical steps known as the Zeldovich mechanism. NOx formation occurs at temperature above 1500^0C, and the rate of formation increases rapidly with increasing temperature (17). The nitrogen oxides emission is directly related to the engine combustion chamber temperatures, which in turn indicated by the prevailing exhaust gas temperature. Figure 8 shows that the variation of NOx emission for diesel and NOME blends with different load conditions.

The presence of oxygen molecule in biodiesel causes an increase gas temperature resulting in a marginal increase in NOx emissions (18). Higher value of NOx emission is observed for NOME blends compared to diesel and the values are 1100ppm, 1250ppm and 1160ppm respectively for diesel, B20 and B30 blends at full load condition.

3.7 Smoke

Smoke is nothing but solid soot particles suspended in exhaust gas. Biodiesel gives less smoke density as compared to that of petroleum diesel. Improved mixture formation and well atomization spray which varies the smoke. The smoke density for B20 and B30 blends is lower than the diesel and is shown in Figure 9.

Smoke emissions are 8.2% and 5.1% lower than the diesel for B20 and B30 blends respectively at full load conditions. Improved oxidation process, higher combustion temperature, extended duration of combustion and rapid flame propagation improves combustion process in B20 and B30 blends and reduces the smoke.

3.8 Pressure-Crank Angle

Figure 10 shows the comparison of the cylinder pressure with crank angle for NOME blends B20 and B30 with diesel at full load condition. In a compression ignition engine, the peak cylinder pressure depends on the burned fuel fraction during the premixed burning phase at the initial stage of combustion. The cylinder pressure characterizes the ability of the fuel to mix well with air and burn (19). The NOME blend produced higher cylinder pressure compared to diesel. The presence of oxygen molecule in biodiesel leads to better combustion and resulting in higher cylinder temperature and pressure. Due to the high viscosity and low volatility of biodiesel blends, there is occurrence of a short ignition delay for esters blend than diesel. The reason for shorter ignition delay could be due to complex and rapid preflame chemical reaction at high temperatures (22). The peak pressure occurred in the range of 5^0-10^0 after TDC and shown in Figure 10. The peak pressure obtained for diesel, B30 and B20 blends are 62.9bar, 68.4bar and 72.1bar, respectively.

3.9 Heat Release Rate

The heat release rate is used to identify the start of combustion, the fraction of fuel burned in the premixed mode and differences in combustion rates of fuels. The amount of heat release in the premixed combustion of a CI engine depends on the ignition delay, air fuel mixing rate and the heating value of the fuel (2). Figure 11 illustrates heat release rate with respect to the crank angle at full load condition. NOME blends produces higher heat release rate compared to diesel this could be due to shorter ignition delay for NOME blends. The presence of the oxygen molecule in NOME results in the air mixed fuel in the cylinder to burn completely and increases the heat release rate (22).

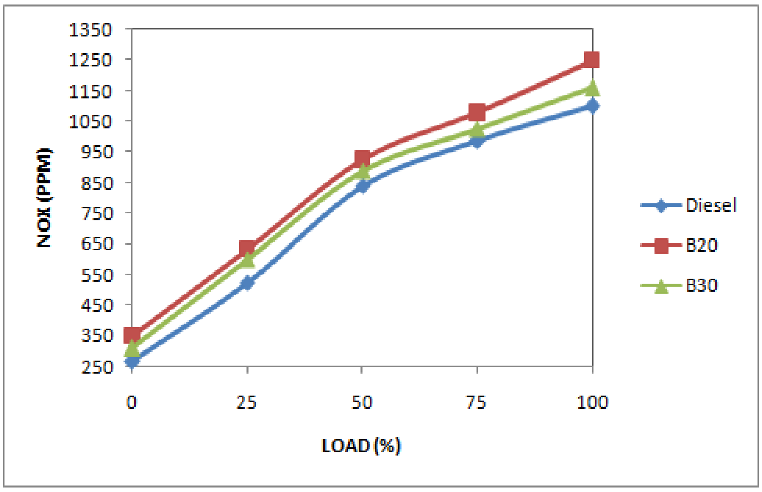

Fig. 8. Variation of Oxides of nitrogen emission with load.

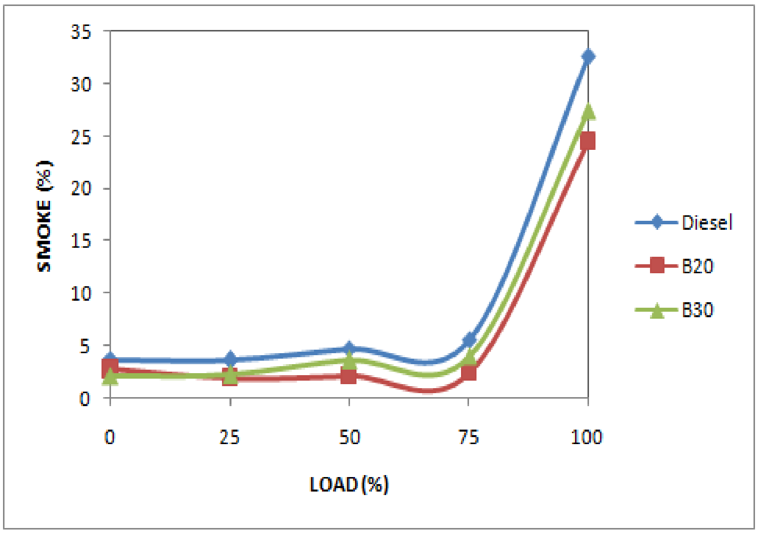

Fig. 9. Variation of Smoke emission with load.

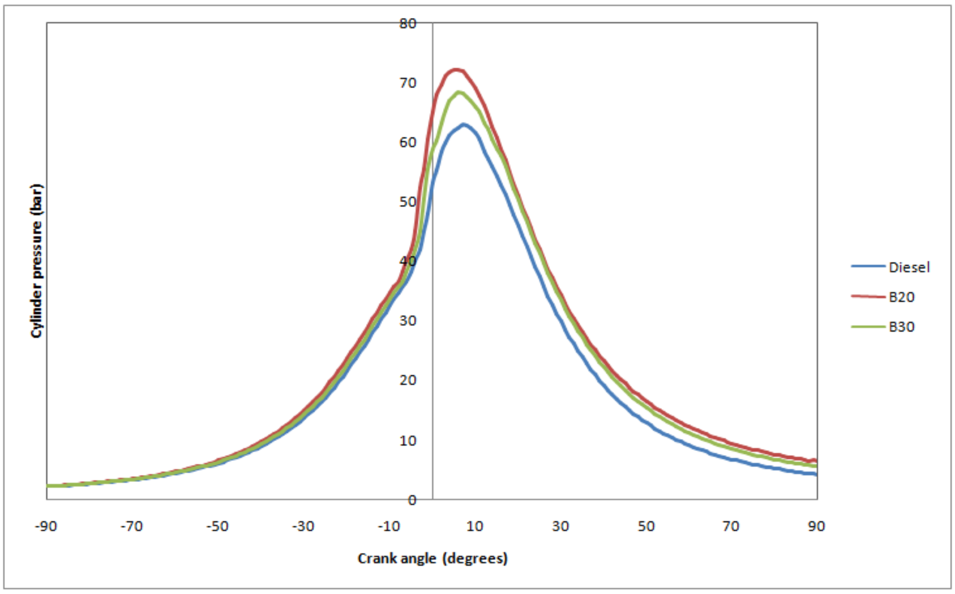

Fig. 10. Variation of pressure crank angle with load.

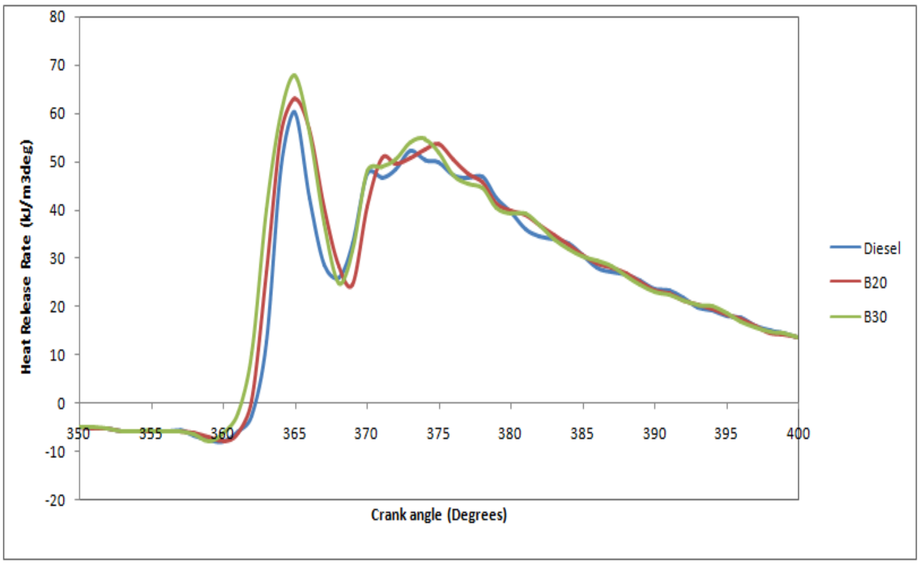

Fig. 11. Variation of heat release rate with load.

4. CONCLUSIONS

The performance, emission and combustion characteristics of a single cylinder C.I engine fuelled with NOME blend B20 and B30 with diesel have been analyzed, and the same has been compared with diesel. The conclusion of the present study is summarized as follows.

- BTE of C.I engine using NOME blend B20, B30 and diesel are 28.32%, 27.69% and 26.74% respectively at full load condition, the efficiency with B20 blend is higher as compared to B30 and diesel.
- Exhaust emissions, especially carbon monoxide (CO), hydro carbon (HC) are decreased with NOME blends as compared to diesel.
- NOx emissions for B20 and B30 are higher as compared to diesel. The values of NOx emissions are 150 ppm and 60 ppm higher than the diesel for B20 and B30 respectively.
- In comparison with diesel, the smoke emissions from B20 and B30 are lesser by about 5.1% and 8.1% respectively at full load.
- Higher heat release rates and peak pressure are observed with B20 and B30 blends as compared to diesel.
- For NOME, the study found B20 blend gives better performance, emissions and combustion characteristics as compared to B30 and diesel.

REFERENCES

[1] Gajendra Babu M.K. and K.A Subramanian. 2013. Alternative Transportation Fuels – Utilisation in Combustion Engines. CRC Press, Taylor and Francis Group, ISBN: 978-1-4398-7281-9978143987281-9.

[2] Agarwal A.K., 2007. Biofuels (alcohols and biodiesel) application as fuels for internal combustion engines. *Progress in Energy and Combustion Science* 33, 233-271.

[3] Puhan S., Vedaraman N., Rambrahamam B.V., and Nagarajan G., 2005. Mahua (Madhuca indica) seed oil: A source of renewable energy in India. *Journal of Scientific and Industrial Research* 64: 890-896.

[4] Lapuerta M., Armas O., Rodriguez-Fernandez J., 2008. Effect of biodiesel fuels on diesel engine emissions. *Progress in Energy and Combustion Science* 34: 198-223.

[5] Altin R., Cetinkaya S., Yucesu H.S., 2001. The potential of using vegetable oil fuels as fuel for diesel Engines. *Energy Conversion and Management* 42: 529-538.

[6] Ramadhas A.S., Jayaraj S., Muraleedharan C., 2005. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. *Renewable Energy* 30: 1789-1800.

[7] Canakci M. and J.H. Van Gerpen, 2003. Comparison of engine performance and emissions for petroleum diesel fuel, yellow grease biodiesel, and soybean oil biodiesel. *American Society of Agricultural Engineers* 46(4): 937-944.

[8] Balaji G. and M. Cheralathan. 2014. Study of antioxidant effect on oxidation stability and emissions in a methyl ester of neem oil fuelled DI diesel engine. *Journal of the Energy Institute*. 87:1-8.

[9] Muralidharan K. and D. Vasudevan. 2011. Performance, emission and combustion characteristics of a variable compression ratio engine using methyl esters of waste cooking oil and diesel blends. *Applied Energy* 88: 3959-3968.

[10] Buyukkaya E., 2010. Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics. *Fuel* 89: 3099-3105.

[11] Banapurmath N.R., Tewari P.G., Yaliwal V.S., Kambalimath S. and Basavarajappa Y.H., 2009. Combustion characteristics of a 4-stroke CI engine

operated on Horge oil, Neem and Rice Bran oil when directly injected and dual fuelled with producer gas induction. *International Journal of Renewable Energy* 34: 1877-1884.
[12] Nantha Gopal K., Pal A., Sharma S., Samanchi C., Sathyanarayanan K., and Elango T., 2014. Investigation of emissions and combustion characteristics of a CI engine fueled with waste cooking oil methyl ester and diesel blends. *Alexandria Engineering Journal* 53: 281–287.
[13] de Almeida S.C.A., Belchior C.R., Nascimento M.V.G., Vieira L.S.R., and Fleury G., 2002. Performance of a diesel generator fuelled with palm oil. *Fuel* 81: 2097-2102.
[14] Narayana Reddy J. and A. Ramesh, 2006. Parametric studies for improving the performance of a Jatropha oil-fuelled compression ignition engine. *Renewable Energy* 31: 1994–2016.
[15] Sardar N., Ahmad M., Khan M.A., Ali S., Zafar M., Khalid N. and Sultana S., 2011. Prospects and potential of non edible neem oil biodiesel based on physico-chemical characterization. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 33(15): 1422-1430.
[16] Haik Y., Selim M.Y.E., and Abdulrehman T., 2011. Combustion of algae oil methyl ester in an indirect injection diesel engine. *Energy* 36: 1827-1835.
[17] Hoekman S.K. and C. Robbins. 2012. Review of the effect of biodiesel on NOx emissions. *Fuel Processing Technology* 96: 237-249.
[18] Nambi M.N., Hoque S.M.N., and Akhter M.S., 2009. Karanja (Pongamania Pinnata) biodiesel production in Bangladesh, characterization of karanja biodiesel and its effect on diesel emissions. *Fuel Processing Technology* 90: 1080-1086.
[19] Heywood J.B., 1988. Internal combustion engines fundamentals. McGraw-hill.
[20] Devan P.K. and N.V. Mahalakshmi. 2009. A study of the performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil- eucalyptus oil blends. *Applied Energy* 86: 675-680.
[21] Ragit S.S., Mohapatra S.K., Kundu K. and Gill P., 2011. Optimization of neem methyl ester from transesterification process and fuel characterization as a diesel substitute. *Biomass and Bioenergy* 3(5): 1138-1144.
[22] Kumar R. and A.K. Dixit, 2014. Combustion and emission characteristics of variable compression ignition engine fueled with jatropha curcas ethyl ester blends at different compression ratio. *Journal of Renewable Energy*, Volume 2014, Article ID 872923, 12 pages. http://dx.doi.org/10.1155/2014/872923.
[23] Yu C.W., Bari S. and Ameen A., 2002. A comparison of combustion characteristics of waste cooking oil with diesel as fuel in a direct injection diesel. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 216: 237-243, DOI: 10.1243/0954407021529066.

APPENDIX

NOME	Neem oil methyl ester
CN	Cetane number
CO	Carbon monoxide
CO2	Carbon dioxide
NOx	Nitrogen dioxide
HC	Hydro carbon
BSFC	Brake specific fuel consumption
WCO	Waste cooking oil
CA	Crank angle
BTDC	Before top dead centre
BTE	Brake thermal efficiency
EGT	Exhaust gas temperature